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Estimated genetic parameters for carcass traits of Brahman cattle^{1,2,3}

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ABSTRACT: Heritabilities and genetic and phenotypic correlations were estimated from feedlot and carcass data collected from Brahman calves (n = 504) in central Florida from 1996 to 2000. Data were analyzed using animal models in MTDFREML. Models included contemporary group (n = 44; groups of calves of the same sex, fed in the same pen, slaughtered on the same day) as a fixed effect and calf age in days at slaughter as a continuous variable. Estimated feedlot trait heritabilities were 0.64, 0.67, 0.47, and 0.26 for ADG, hip height at slaughter, slaughter weight, and shrink. The USDA yield grade estimated heritability was 0.71; heritabilities for component traits of yield grade, including hot carcass weight, adjusted 12th rib backfat thickness, loin muscle area, and percentage kidney, pelvic, and heart fat were 0.55, 0.63, 0.44, and 0.46, respectively.

Heritability estimates for dressing percentage, marbling score, USDA quality grade, cutability, retail yield, and carcass hump height were 0.77, 0.44, 0.47, 0.71, 0.5, and 0.54, respectively. Estimated genetic correlations of adjusted 12th rib backfat thickness with ADG, slaughter weight, marbling score, percentage kidney, pelvic, and heart fat, and yield grade (0.49, 0.46, 0.56, 0.63, and 0.93, respectively) were generally larger than most literature estimates. Estimated genetic correlations of marbling score with ADG, percentage shrink, loin muscle area, percentage kidney, pelvic, and heart fat, USDA yield grade, cutability, retail yield, and carcass hump height were 0.28, 0.49, 0.44, 0.27, 0.45, -0.43, 0.27, and 0.43, respectively. Results indicate that sufficient genetic variation exists within the Brahman breed for design and implementation of effective selection programs for important carcass quality and yield traits.

Key Words: Brahman, Carcass Quality, Carcass Yield, Feedlots, Genetic Parameters

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Introduction

Although the Brahman breed has been an important part of the U.S. cow-calf industry (primarily for its contribution in crossbreeding programs), research has reported that Brahman-cross beef often has lower quality grades and more variable tenderness than that of many

Bos taurus breeds (Crouse et al., 1989). If within-breed selection could improve marbling and(or) tenderness of Brahman beef, cow-calf producers would be able to address industry concern for these traits and continue to benefit from the excellent performance of Brahman-cross cows without receiving carcass discounts at marketing. Genetic parameters of various feedlot and carcass traits in *Bos taurus* cattle have been reviewed (Marshall, 1994), analyzed, and summarized (Koots et al., 1994a,b). Some genetic parameters for carcass traits of percentage Brahman (Crews and Franke, 1998; Elzo et al., 1998) and Brahman-influenced American breeds (O'Connor et al., 1997; Moser et al., 1998) have been reported. Limited genetic parameter information for carcass traits of straightbred Brahman cattle exists as part of results from Elzo et al. (1998). The objectives of this study were to estimate heritabilities, genetic correlations, and phenotypic correlations of feedlot and carcass traits of straightbred Brahman calves.

Materials and Methods

At the Subtropical Agricultural Research Station (STARS) located near Brooksville, FL, feedlot and car-

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²Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product to the exclusion of others that may also be suitable.

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cass data of Brahman calves ($n = 504$, including 258 heifers and 246 steers) sired by 22 Brahman bulls were collected over 5 yr (1996 through 2000). Most of the cows that had calves in this project were born and raised in the STARS Brahman herd. Some ($n = 19$) were high percentage Brahman that descended from a group of commercial cows purchased in the late 1970s. A few cows were $\frac{1}{2}$ Brahman $\frac{1}{2}$ Nellore ($n = 11$) or $\frac{3}{4}$ Brahman $\frac{1}{4}$ Nellore ($n = 2$).

Beginning in 1994, cows were separated into breeding herds of approximately 30 to 50 and each group was exposed to a single Brahman sire. Five or six registered Brahman sires were used each year; most were loaned to STARS by purebred producers. In each year after the first, one bull that sired calves in the previous year was again used to facilitate comparison of data across years. Although two of the sires were half-siblings, most of the relatedness among the 22 bulls was due to two common ancestors, who were themselves sire and son. These two bulls are prominent ancestors in many Brahman bloodlines. The average number of progeny per sire was 22.9 and ranged from seven for a sire used in the 1996 breeding season (this bull was injured early in the breeding season and removed from the breeding pasture) to 50 for a sire with calves born in 1998 and 1999.

The breeding season began on approximately March 20 of each year and lasted for 105 d. Calves were born from late December through late April or early May of each year. Shortly after birth, calves were weighed and tagged, and bull calves were castrated. They were weaned in September of each year at approximately 7 mo of age. After a 2- to 3-wk postweaning conditioning period, calves were sorted into feedlot pens by sex and weight. All but the very smallest calves were fed. Calves were started on a diet consisting of approximately 55% corn, 25% cottonseed hulls and/or ground hay, 15% supplement (which contained melengestrol acetate for heifers and monensin, vitamin A, and microminerals for all calves), and 5% molasses. They were gradually changed to the final diet over approximately 28 d. The final diet consisted of 72.5% corn, 15% cottonseed hulls and/or ground hay, 7.5% supplement, and 5% molasses. Steer and heifer calves were implanted with Synovex-S and Synovex-H, respectively, both at 0 and 112 d of feeding. Calf weights and hip heights were recorded every 28 d. After approximately 140 d of feeding, external fat cover was estimated using real-time ultrasound, in conjunction with monthly data collection. When the median backfat of the animals in a pen was 10 mm, full and shrunk weights were obtained on consecutive days, hip height was measured, and the entire pen was slaughtered at Central Packing Co. in Center Hill, FL. Approximately 18 h after slaughter, carcasses were graded for USDA quality and yield factors. No other postslaughter treatments, specifically electrical stimulation, were applied to carcasses.

Table 1. Simple statistics for feedlot and carcass traits of Brahman cattle

Trait	n	\bar{x}	SD	CV
ADG, kg	504	1.10	0.17	15.45
Hip height, cm	504	134.81	6.63	4.91
Slaughter wt, kg	504	443.61	55.7	12.56
Shrink, %	504	3.37	1.34	39.82
Adj. fat thickness, mm	504	13.34	3.67	27.48
Hot carcass wt, kg	503	283.39	37.82	13.34
Dressing percentage	503	63.85	2.27	3.55
Loin muscle area, cm ²	504	72.55	7.71	10.63
KPH fat, %	504	2.29	0.67	29.11
Yield grade	503	3.08	0.56	18.16
Marbling score ^a	504	323.75	57.19	17.67
Quality grade ^b	504	525.95	42.87	8.15
Cutability, % ^c	503	49.91	1.40	2.80
Retail yield, kg ^d	503	141.31	18.28	12.94
Hump height, cm	494	15.76	3.59	13.34

^a200 to 299 = Traces; 300 to 399 = Slight; 400 to 499 = Small.

^b400 to 499 = Standard; 500 to 599 = Select; 600 to 699 = Choice.

^cCutability = $51.34 - (2.277 \times \text{adjusted fat thickness}) - (0.462 \times \% \text{ kidney, pelvic, and heart fat}) - (0.0205 \times \text{hot carcass weight}) + (0.1147 \times \text{loin muscle area})$.

^dRetail yield = hot carcass weight \times % cutability.

Traits Evaluated

The evaluated traits, numbers of records, and simple statistics are presented in Table 1. Slaughter weight was the final (shrunk) weight. Shrink was analyzed as final full weight minus shrunk weight, as a percentage of full weight. Dressing percentage was hot carcass weight as a percentage of slaughter weight. Fat thickness was measured on the carcass at the 12th rib and adjusted based on overall carcass fatness according to USDA (1990) guidelines. Marbling score was evaluated numerically: Devoid = 100 to 199; Traces = 200 to 299; Slight = 300 to 399; Small = 400 to 499; Modest = 500 to 599; Moderate = 600 to 699. In a similar manner, USDA quality grade was evaluated numerically: Standard = 400 to 499; Select = 500 to 599; Choice = 600 to 699; and Prime = 700 to 799. Although direct measurements were not taken, percentage yield of boneless, closely trimmed retail cuts from the round, loin, rib, and chuck (cutability) was estimated using the equation originally proposed by Murphey et al. (1963): $51.34 - (2.277 \times \text{adjusted fat thickness over the 12th rib}) - (0.462 \times \% \text{ kidney, pelvic, and heart fat}) - (0.0205 \times \text{hot carcass weight}) + (0.1147 \times \text{loin muscle area})$. Subsequently, retail product yield was estimated as the product of cutability and hot carcass weight. Carcass hump height was measured from the most dorsal point of the hump to the dorsal edge of the ligamentum nuchae.

Statistical Methods

Model components were identified using the MIXED procedures of SAS (SAS Inst. Inc., Cary, NC). Contemporary group was defined as a group of calves of the same sex, fed in the same pen, and slaughtered on the

same date; it was verified as a highly significant fixed model component in analyses of all traits. There were 44 contemporary groups for all traits in the study, with an average of 11.45 calves per group. All traits were analyzed with calf age in days at slaughter as a continuous variable ($P \leq 0.05$).

Parameters were estimated in animal models using restricted maximum likelihood procedures of MTDFREML (Boldman et al., 1995). The full relationship matrix was included by incorporation of all available pedigree data of the STARS Brahman herd and three to five generations of pedigree information of the sires used in the project. Heritabilities (h^2) were estimated using single-trait analyses. Starting values of the genetic and environmental variances for single-trait analyses were guessed using results from analyses (MIXED procedures) in SAS. Single-trait analyses were run to low (10^{-3}) and later to higher (10^{-6} and 10^{-9}) levels of convergence. Two-trait analyses were conducted to estimate the genetic (r_g) and phenotypic (r_p) correlations between pairs of traits. Initial two-trait analyses were conducted holding the genetic and environmental variance estimates (from single-trait analyses) constant to a low convergence criterion (10^{-3}) in order to estimate covariances between traits; starting values for these covariances were guessed. Cold restarts from apparently converged estimates (with no variances held constant) were again run to a low level of convergence. Cold restarts were then repeated until $-2 \log$ likelihood did not change in the first three decimal positions (it was assumed that changes beyond the third decimal were not important). These procedures were repeated, running to a high level of convergence (10^{-9}). Convergence to a global maximum was checked using one to four final cold restarts from converged estimates.

Results and Discussion

Heritabilities

Estimated heritabilities for feedlot traits are shown in Table 2. The h^2 estimate of 0.64 for ADG was higher than estimates from the literature (0.19 to 0.57). The closest estimates were 0.52 for Hereford (Benyshek, 1981), 0.57 for crossbred cattle of Cycles I, II, and III of the Germ Plasm Evaluation (GPE) at the R. L. Hruska Meat Animal Research Center (MARC) in Nebraska (Koch et al., 1982), and 0.48 reported by Gregory et al. (1995) in *Bos taurus* composites (MARC I, II, and III) of the Germ Plasm Utilization (GPU) program at MARC. Lower to moderate estimates (0.19 to 0.44) were reported by Lamb et al. (1990) for Hereford bulls, Johnston et al. (1992) in Charolais (Canadian data), Shackelford et al. (1994) in crossbred cattle from GPE and GPU, Gregory et al. (1995) for GPU straightbred cattle (breeds that comprise MARC composites), Hirooka et al. (1996) in Japanese Brown, and Fouilloux et al. (1999) in Limousin and Charolais (French data). The hip height h^2 of 0.67 was less than that for Brahman re-

Table 2. Estimated genetic (σ_g), environmental (σ_e), and phenotypic (σ_p) SD and heritabilities (h^2) of feedlot and carcass traits of Brahman calves

Trait	σ_g	σ_e	σ_p	h^2
ADG, kg	0.113	0.085	0.142	0.64
Hip height, cm	3.378	2.391	4.139	0.67
Slaughter wt, kg	22.033	23.239	32.024	0.47
Shrink, %	0.541	0.915	1.063	0.26
Adj. fat thickness, mm	3.252	2.474	4.086	0.63
Hot carcass wt, kg	16.129	14.553	21.725	0.55
Dressing percentage	1.605	0.871	1.826	0.77
Loin muscle area, cm ²	4.101	4.631	6.185	0.44
KPH fat, %	0.411	0.441	0.602	0.46
Yield grade	0.444	0.283	0.526	0.71
Marbling score ^a	34.747	39.453	52.572	0.44
Quality grade ^b	26.838	28.685	39.282	0.47
Cutability, % ^c	1.117	0.717	1.327	0.71
Retail yield, kg ^d	6.980	7.044	9.917	0.50
Hump height, cm	1.967	1.817	2.678	0.54

^a200 to 299 = Traces; 300 to 399 = Slight; 400 to 499 = Small.

^b400 to 499 = Standard; 500 to 599 = Select; 600 to 699 = Choice.

^cCutability = $51.34 - (2.277 \times \text{adjusted fat thickness}) - (0.462 \times \% \text{ kidney, pelvic, and heart fat}) - (0.0205 \times \text{hot carcass weight}) + (0.1147 \times \text{loin muscle area})$.

^dRetail yield = hot carcass weight \times % cutability.

ported by Vargas et al. (2000) for hip height at 18 mo (0.87). The data for Vargas et al. (2000) were earlier records of the STARS Brahman herd, at a time when protocol dictated positive assortative mating based on hip height. The slaughter weight h^2 (0.47) was higher than others reported in literature, including 0.15 for Limousin- and Charolais-sired cattle (Wulf et al., 1996), 0.28 for Korean Native (Hanwoo) cattle (Lee et al., 2000a), 0.26 and 0.37 for straightbred and composite cattle of GPU (Gregory et al., 1995), 0.37 for GPE Cycle V crossbreds (Wheeler et al., 2001), 0.41 for Hereford bulls (Lamb et al., 1990), and 0.42 for Hereford steers and heifers (Veseth et al., 1993). The shrink h^2 (0.26) of the present study was less than half than that reported (0.53) in an early Hereford study (Shelby et al., 1963).

The component traits of USDA yield grade have been studied more than the composite trait. The hot carcass weight h^2 of 0.55 was within the range (0.31 to 0.68) reported by Marshall (1994) but larger than the average of 0.36 reported by Koots et al. (1994a). Other *Bos indicus* estimates included that for Brahman (0.39) and $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ Brahman (0.3, 0.37, and 0.37, respectively; the other breed fraction was Angus) by Elzo et al. (1998), and 0.59 for Brangus (Moser et al., 1998). Crews and Franke (1998) estimated heritabilities within and across three breed groups of steers of differing fractions of Brahman inheritance. The three groups included 1) greater than $\frac{1}{2}$ Brahman, 2) $\frac{1}{4}$ to $\frac{1}{2}$ Brahman, and 3) less than $\frac{1}{4}$ Brahman. Although the authors reported significant heterogeneity of variance due to the different breed groups for hot carcass weight, there was a relatively narrow range of h^2 estimates (0.28 to 0.35 for different combinations of data). Recent estimates from other breeds encompassed values from near 0.09

(Johnston et al., 1992; Wulf et al., 1996) to 0.2 to 0.4 for GPU and GPE cattle (Gregory et al., 1995; Wheeler et al., 2001), Japanese Brown (Hirooka et al., 1996), Angus (Elzo et al., 1998), Angus- and Simmental-sired calves (Hassen et al., 1999), and Simmental (Shanks et al., 2001). High values included 0.49 across beef and dairy (including *Bos taurus* and *Bos indicus*) breed types in New Zealand (Morris et al., 1999), 0.5 for steers of GPE Cycles I through IV (Splan et al., 1998), and 0.6 for Shorthorn (Pariacote et al., 1998).

Estimated heritabilities for the other component traits of USDA yield grade were generally consistent with most other reported literature. The loin muscle area h^2 of 0.44 was less than that for Brahman (0.53) but greater than the estimates for percentage Brahman steers (0.32 to 0.34) reported by Elzo et al. (1998). Crews and Franke (1998) reported significant heterogeneity of variance among the different breed groups for loin muscle area and a large range (0.4 to 0.75) within and across breed groups (the highest h^2 of their analyses were estimated for the breed group composed of steers with less than $\frac{1}{4}$ Brahman). Most reported h^2 for loin muscle area ranged from 0.15 (Hassen et al., 1999) to 0.6 (Van Vleck et al., 1992; Splan et al., 1998), but Wheeler et al. (2001) reported 0.69 and Pariacote et al. (1998) reported the highest estimate of 0.97. Marshall (1994) listed a similar range (0.01 to 0.6), and Koots et al. (1994a) reported an average h^2 of 0.4. The percentage kidney, pelvic, and heart fat h^2 of 0.46 was greater than the estimates for Brahman (0.14), percentage Brahman (0.01 to 0.07), and Angus (0.02) reported by Elzo et al. (1998), but more similar to h^2 of 0.28, 0.37, 0.45, and 0.48 reported by Wheeler et al. (2001), Veseth et al. (1993), Pariacote et al. (1998), and Splan et al. (1998), respectively. Koch et al. (1982) reported the highest percentage kidney, pelvic, and heart fat h^2 of 0.83. The 12th rib fat thickness h^2 of the present study was 0.63, higher than estimates reported for Brahman (0.24) and $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ Brahman (0.18, 0.03, and 0.02, respectively) by Elzo et al. (1998). It was also higher than the range of estimates (0.02 to 0.38) for the different percentage Brahman groups of Crews and Franke (1998). In that study, the group of steers with $\frac{1}{4}$ to $\frac{1}{2}$ Brahman background had higher additive genetic variances across the different combinations of data (and therefore h^2) than steers with less than $\frac{1}{4}$ Brahman or those with more than $\frac{1}{2}$ Brahman. Other fat thickness h^2 estimates in literature ranged from 0.1 (Shanks et al., 2001) to 0.84 (Wheeler et al., 2001). The USDA yield grade h^2 (0.71) was similar to the estimates (0.54, 0.76, and 0.85, respectively) of Pariacote et al. (1998), Wulf et al. (1996), and Wheeler et al. (2001) but much larger than that (0.24) of Lamb et al. (1990) and those (0.08 to 0.47) of Crews and Franke (1998).

The heritability estimate for cutability (0.71) was most similar to that (0.66) for Hereford cattle (Dinkel and Busch, 1973). Lower estimates include 0.28 in Angus, Hereford, and Shorthorn steers (Cundiff et al., 1971) and 0.23 in Hereford bulls (Lamb et al., 1990).

Koots et al. (1994a) reported a weighted h^2 for cutability-type traits of 0.47, and Marshall (1994) listed a range from 0.18 to 0.63. Other estimates for cutability-type traits from the literature included 0.12 for Simmental (Woodward et al., 1992) and 0.52 for Australian Brahman, Belmont Red, and Santa Gertrudis (Robinson et al., 1998). The h^2 for retail yield (0.5) was within a range of estimates that included 0.28 (Gregory et al., 1995), 0.33 (Hassen et al., 1999), 0.36 (Robinson et al., 1998), 0.45 (Shackelford et al., 1994), 0.38 to 0.58 (Marshall, 1994), and 0.28 to 0.57 (Crews and Franke, 1998). The dressing percentage h^2 of 0.77 was higher than literature estimates that were (mostly) from 0.2 to 0.4 (Gregory et al., 1995; Robinson et al., 1998; Morris et al., 1999). The highest dressing percentage h^2 from literature (0.62) was that of Lee et al. (2000a).

The marbling score h^2 (0.44) was in agreement with most literature reports and close to the h^2 of 0.47 for USDA quality grade. Marshall (1994) reported a range of marbling score h^2 from 0.23 to 0.47, and Koots et al. (1994a) reported a weighted average h^2 of 0.3. It was over twice the Brahman estimate of 0.16 (Elzo et al., 1998) and similar to that (0.52) reported by O'Connor et al. (1997) in $\frac{3}{8}$ and $\frac{1}{2}$ Brahman cattle and *Bos taurus* crossbred cattle. Elzo et al. (1998) reported lower h^2 of 0.13, 0.19, and 0.23 in $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{8}$ Brahman steers, and Crews and Franke (1998) reported a range from 0.09 to 0.37. Estimates in British cattle mostly ranged from 0.26 to 0.35 (Arnold et al., 1991; Veseth et al., 1993; Wilson et al., 1993), but Elzo et al. (1998) reported 0.14 for Angus steers and Pariacote et al. (1998) reported 0.88 for Shorthorn cattle. Estimates among Continental European cattle were lower and ranged from 0.09 to 0.26 (Johnston et al., 1992; Woodward et al., 1992; Shanks et al., 2001). Marbling score h^2 from GPE studies ranged from 0.4 to 0.71 (Van Vleck et al., 1992; Barkhouse et al., 1996; Wheeler et al., 2001), and estimates from GPU were 0.45 to 0.55 (Gregory et al., 1995). Lee et al. (2000a) and Hirooka et al. (1996) reported marbling score estimates of 0.35 and 0.4, respectively, for Asian *Bos taurus* cattle.

The moderate h^2 for marbling score is of considerable importance. Since the report of Crouse et al. (1989), one persistent criticism of the Brahman breed has been that percentage Brahman carcasses tend to have lower marbling scores (and resultant lower quality grades) relative to other beef breeds. Genetic differences in marbling score within the Brahman breed recently have been reported in Australia (Gazzola et al., 1998), where a Brahman sire was identified whose steer progeny (out of Brahman, Belmont Red, British, and Brahman-British cross cows) had significantly higher marbling scores than steers sired by other Brahman bulls. Even though the h^2 of marbling score estimated by Elzo et al. (1998) in Brahman and percentage Brahman carcasses were low, the higher h^2 of O'Connor et al. (1997) in crossbred Brahman and *Bos taurus* steers, the results of Gazzola et al. (1998), and the h^2 of marbling score and USDA quality grade of the present study provide a basis of

support for sire selection within the breed for marbling score (and quality grade) improvement.

Genetic Correlations

Most of the r_g involving fat thickness (Table 3) were larger than literature reports. The r_g of fat thickness with marbling (0.56) was larger than all except the upper end (0.64) of the range listed by Marshall (1994) and most similar to that (0.44) of Gregory et al. (1995). Many reported estimates were low to moderately positive (Koch et al., 1982; Pariacote et al., 1998; Shanks et al., 2001). Elzo reported no genetic relationship (0.03), and two studies reported low negative estimates (Wilson et al., 1993; Hirooka et al., 1996). The large positive r_g of fat thickness with percentage kidney, pelvic, and heart fat (0.63) was larger than the literature range of -0.21 to 0.1 (Koch et al., 1982; Elzo et al., 1998; Pariacote et al., 1998). The fat thickness-yield grade r_g (0.93) was similar to that (0.67) of Pariacote et al. (1998) but much larger than that (0.18) of Lamb et al. (1990); it should again be noted that the data of the latter study were from bulls. The fat thickness-ADG r_g (0.49) was similar to the estimate of 0.31 reported by Hirooka et al. (1996) and larger than the low values (0.05 to 0.19) of early studies (Shelby et al., 1963; Koch et al., 1982; Koots et al., 1994b). The r_g of fat thickness with slaughter weight was twice that (0.23) of Gregory et al. (1995) and almost three times larger than that (0.14) of Lamb et al. (1990). The r_g of fat thickness with dressing percentage (0.39) was of opposite sign of the estimates (-0.23 and -0.16 , respectively) of Dinkel and Busch (1973) and Pariacote et al. (1998). The r_g of fat thickness with retail yield (0.29) similarly was of opposite sign of those of Koch et al. (1982) and Hassen et al. (1999), which were -0.34 and -0.36 , respectively.

The r_g of marbling score and loin muscle area of 0.44 was in general agreement with those (0.48 to 0.57) reported by Lamb et al. (1990), Veseth et al. (1993), and Shanks et al. (2001). It was greater than the estimates reported for Brahman (-0.01) and percentage Brahman steers (-0.08 to -0.06) by Elzo et al. (1998); however, the authors emphasized that asymptotic SE of these correlations were likely large. Other estimates from the literature were negative and of low to moderate (-0.24 to -0.02) magnitude; Koots et al. (1994b) reported an average r_g of -0.21 that was in reasonable agreement with more recent estimates (Gregory et al., 1995; Lee et al., 2000b; Wheeler et al., 2001). However, there were low positive r_g (0.12 and 0.13) reported for these traits (Hirooka et al., 1996; Wulf et al., 1996).

The current system of assigning value to beef carcasses in the United States necessitates consideration of the relationships between marbling score and lean yield-type traits in selection programs for these traits. Genetic correlations of marbling score with the various lean yield traits were moderate to large. The r_g of marbling score with cutability (-0.43) was reasonably similar to low to moderate negative (-0.37 to -0.11) esti-

mates (Woodward et al., 1992; Gregory et al., 1995; Shanks et al., 2001). Dinkel and Busch (1973) reported a positive r_g (0.26) for this pair of traits. The r_g for marbling score with USDA yield grade (0.45) was in agreement with the results of Lamb et al. (1990), Wulf et al. (1996), Pariacote et al. (1998), and Wheeler et al. (2001), which were 0.32, 0.04, 0.26, and 0.6, respectively. The r_g of marbling score with retail yield (0.27) was larger than the -0.13 reported by Cundiff et al. (1971) and -0.02 reported by Koch et al. (1982).

The r_g of marbling score with percentage kidney, pelvic, and heart fat (0.27) was consistent with the positive estimates of Koch et al. (1982), Veseth et al. (1993), and Pariacote et al. (1998), which were 0.29, 0.59, and 0.1, respectively. It was larger than those for Brahman (0.02), percentage Brahman (0.02 to 0.04), or Angus (0.07) of Elzo et al. (1998). The r_g of marbling score with slaughter weight was 0.27, consistent with other reported values (0.27 to 0.6) (Koots et al., 1994b; Gregory et al., 1995; Wulf et al., 1996).

Genetic correlations of dressing percentage with several traits were quite different from other reports. The r_g of dressing percentage with loin muscle area was 0.02, and though Veseth et al. (1993) reported a similar value of -0.11 , others reported within a range from 0.36 to 0.79 (Koots et al., 1994b; Pariacote et al., 1998; Morris et al., 1999). The r_g of dressing percentage and ADG (-0.01) was within a range reported in the literature from -0.21 to 0.36 (Veseth et al., 1993; Koots et al., 1994b; Fouilloux et al., 1999). The r_g of dressing percentage with USDA yield grade was 0.48; the Shorthorn estimate of Pariacote et al. (1998) was -0.56 .

The r_g of shrink with fat thickness (-0.26), slaughter weight (0.07), dressing percentage (0.39), hot carcass weight (0.21), and loin muscle area (0.36) were different from the estimates (-0.14 , -0.29 , -0.02 , and -0.06 for cold carcass weight, and 0.1, respectively) reported by Shelby et al. (1963). Shrink has not since been studied extensively.

Carcass hump height is highly heritable (Table 2). There has been recent interest in using carcass hump height for identification of and assignment of value to *Bos indicus* carcasses (Sherbeck et al., 1996; Wulf and Page, 2000). Results of the present study suggest that selection for this trait (within the Brahman breed) would produce large correlated responses in other traits (Table 3), because many of the r_g involving hump height were moderate (marbling score, quality grade and percentage kidney, pelvic, and heart fat) or large (adjusted backfat thickness, hot carcass weight, yield grade, and cutability).

The r_g that differed most from published work included many involving fat thickness, dressing percentage, and the marbling score-loin muscle area r_g . The results of this study suggest that various physiological development traits in Brahman cattle, including fat deposition throughout the carcass, respond to a pleiotropic set of genes to perhaps a greater extent than what has been observed in *Bos taurus* cattle. Carcass

Table 3. Estimated genetic and phenotypic correlations^a for feedlot and carcass traits of Brahman cattle

Trait	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. ADG		0.13	0.94	-0.01	0.39	0.87	-0.03	0.39	0.26	0.42	0.15	0.14	0	0.81	0.39
2. Hip height	0.24		0.30	-0.02	-0.13	0.14	-0.11	0.04	-0.06	-0.04	-0.09	-0.07	0.05	0.29	-0.08
3. Slaughter wt	0.98	0.22		-0.03	0.37	0.93	-0.01	0.41	0.25	0.42	0.13	0.12	-0.37	0.88	0.27
4. Shrink %	0.07	-0.12	0.07		-0.06	0.06	0.20	0.07	-0.08	-0.08	0.09	0.05	0.06	0.09	0.02
5. Fat thickness ^b	0.49	-0.32	0.46	-0.26		0.43	0.23	0.10	0.28	0.81	0.30	0.31	-0.75	0.19	0.37
6. Hot carcass wt	0.84	0.10	0.90	0.21	0.60		0.24	0.44	0.30	0.48	0.17	0.16	-0.43	0.94	0.34
7. Dressing percentage	-0.01	-0.25	0.08	0.39	0.42	0.47		0.16	0.18	0.24	0.16	0.13	-0.22	0.31	0.23
8. Loin muscle area	0.58	-0.12	0.60	0.36	0.02	0.52	0.02		0.17	-0.30	0.12	0.10	0.32	0.60	0.16
9. KPH %	0.33	-0.35	0.22	-0.04	0.63	0.27	0.24	0.18		0.43	0.18	0.17	-0.42	0.17	0.19
10. Yield grade	0.41	-0.21	0.40	-0.31	0.93	0.56	0.48	-0.26	0.60		0.26	0.27	-0.93	0.17	0.32
11. Marbling score ^c	0.28	-0.27	0.27	0.49	0.56	0.39	0.35	0.44	0.27	0.45		0.96	-0.23	0.11	0.23
12. Quality grade ^d	0.32	-0.18	0.28	0.49	0.58	0.37	0.26	0.32	0.23	0.48	1.00		-0.23	0.09	0.23
13. Cutability ^e	-0.38	0.21	-0.40	0.26	-0.93	-0.55	-0.48	0.23	-0.67	-0.99	-0.43	-0.45		-0.09	-0.32
14. Retail yield ^f	0.82	0.23	0.89	0.35	0.29	0.92	0.33	0.69	0.04	0.20	0.27	0.24	-0.19		0.25
15. Hump height	0.34	-0.33	0.32	0.17	0.85	0.59	0.66	0.18	0.41	0.72	0.43	0.45	-0.74	0.34	

^aGenetic correlation estimates are below the diagonal; phenotypic correlations are above the diagonal.^bAdjusted backfat thickness was measured at carcass 12th rib, mm.^c200 to 299 = Traces; 300 to 399 = Slight; 400 to 499 = Small.^d400 to 499 = Standard; 500 to 599 = Select; 600 to 699 = Choice.^eCutability = $51.34 - (2.277 \times \text{adjusted fat thickness}) - (0.462 \times \% \text{ kidney, pelvic, and heart fat}) - (0.0205 \times \text{hot carcass weight}) + (0.1147 \times \text{loin muscle area})$.^fRetail yield = hot carcass weight \times % cutability.

hump height appears to also be responsive to such a set of genes. As emphasized by Elzo et al. (1998) for their results, interpretation of the r_g of this study should be tempered by consideration of the relatively small data set. Any extension of results to crossbred populations should be avoided; Crews and Franke (1998) indicated that heterogeneity of variance due to differing fractions of Brahman inheritance was important for several carcass traits, and the results of Elzo et al. (1998) seem to support this.

Phenotypic Correlations

Estimates of r_p are presented above the diagonal of Table 3. Almost all estimates were close to reported values for *Bos taurus* cattle in the literature. However, the r_p for shrink and ADG (−0.01) and shrink and dressing percentage (−0.03) were different from the 0.19 and −0.15 r_p reported by Shelby et al. (1963).

There were low to moderate r_p for carcass hump height with most of the traits of this study. These within-breed r_p are not comparable to the low among-breed simple correlations reported by Sherbeck et al. (1996) and Wulf and Page (2000). In the present study, larger carcass hump heights were phenotypically associated with less desirable values of lean yield traits and were favorably associated, but to a lesser degree, with marbling score and quality grade.

Implications

The results of this study provide estimates of genetic parameters that could be useful in the design of breeding programs for improvement of various carcass traits in Brahman cattle. Many of these estimates are the first reported for this breed. Brahman cattle have been consistently criticized for poor carcass quality and yield performance; these results imply that within-breed improvement in these traits through selection is possible.

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